# BACKGROUND OF THE INVENTION

There is an increasing interest in converting renewable biomass to usable products to avoid consumption of non-replaceable fossil fuels. Biomass is associated with non-fossil organic materials that contain fundamental energy derived from the sun. A biomass is often selected from the group consisting of wood, waste paper and municipal solid waste including an individual or a combination of these materials

Partial oxidation of a biomass is employed to generate a producer gas. Resulting producer gas contains carbon monoxide, hydrogen, and methane and is often used to furnish a fuel to supply energy to an engine or a boiler. Air is provided as needed to maintain partial oxidation of the biomass.

Manufacture of producer gas, is described in Chemical Engineers Handbook third edition, edited by John H Perry, page 1579. The process begins by blowing humidified air into a deep ignited bed of solid fuel usually coal or coke to form an incandescent bed of carbon. The bed of carbon reacts with oxygen in the air to create carbon dioxide which reacts with carbon to form carbon monoxide.

Water vapor, contained in the air, partly reacts with carbon monoxide to form carbon dioxide and hydrogen. The resulting gas contains carbon monoxide, carbon dioxide, hydrogen and nitrogen. .

It is therefore an object of this invention to obviate many of the limitations of the prior art.

A principal object of this invention is to produce hydrogen from a biomass.

A distinct object of this invention is by partial combustion of a biomass to create producer gas.

A further fundamental object of this invention is to provide complete combustion of biomass subjected to partial combustion of a biomass and provide a flue gas..

A fundamental object of this invention is to utilize thermal energy from flue gas to supply heat to compensate energy for endothermic reactions..

An object of this invention is.to remove sensible heat from flue gas to supply heat for reactions and remove moisture from a biomass wherein a biomass of reduced moisture is provided

Another object of this invention is to store hydrogen produced by biomass.

An additional object of this invention is.to remove sensible heat from flue gas to supply heat for reactions and remove moisture from a biomass wherein a biomass of reduced moisture is provided for partial combustion.

With the above and other objects in view, this invention relates to the novel features and alternatives and combinations presently described in the brief description of the invention.

# THEORETICAL BACKGROUND OF THE INVENTION

Producer gas, containing carbon monoxide, water vapor, volatile hydrocarbons and methane is subjected to a steam reforming catalyst to convert volatile hydrocarbons and methane to hydrogen and carbon monoxide. The resulting gas, containing water vapor and carbon monoxide, is subjected to a steam shifting catalyst to convert carbon monoxide and water vapor to hydrogen and carbon dioxide. Both catalytic procedures are applied in the present invention and are presented in Chemical Process Industries, second edition, authored by R. N. Shreve. Within page 135, a steam hydrocarbon process for a propane catalytic reaction is presented by the chemical formula, $C_3H_3 + 3H_2O \rightleftharpoons 2CO_2 + H_2$. Any hydrocarbon, including methane, will be reversibly reformed from water vapor to form hydrogen and carbon monoxide

Catalytic reaction to shift water vapor and carbon monoxide is portrayed by Shreve *op. cit.*, page 136, presented by the chemical formula, $CO + H_2O \rightleftharpoons CO_2 + H_2$.. Thus hydrogen and carbon dioxide are reversibly formed from water vapor from carbon monoxide and water vapor.
These reactions are endothermic and require energy from an external source to maintain temperature within the respective catalyst. Sensible heat from flue gas will supply energy to maintain temperature of the special catalyst. Flue gas, of reduced sensible heat, is employed in a dryer to remove water from a biomass and concluding in a flue gas for release to the atmosphere.

Producer gas is provided by partial combustion of biomass and provides a remainder subject to complete combustion by air to provide flue gas and a residue of thermal energy. The residue is subjected to heat exchange to heat the air used for combustion of the remainder and provides a residue of reduced temperature. Gases from the catalysts, containing sensible heat, are subjected to heat exchange to heat the air used for partial combustion and the gas is of reduced heat.
Accordingly energy is consumed to provide gases containing hydrogen.

# BRIEF DESCRIPTION OF THE INVENTION

The present invention in its broadest aspect, establishes a method to produce a gas containing hydrogen derived from a biomass. Producer gas containing water vapor, hydrocarbons, and carbon monoxide is derived by partial combustion of a biomass. Complete combustion of remains from partial combustion is utilized to form flue gas and a residue containing inorganic solids. The residue is subjected to heat exchange to heat air for combustion and result in a residue of gas of diminished sensible heat. Producer gas is subjected to a catalyst for steam reforming and subjected to a catalyst for steam shifting gas derived from steam reforming. Thus carbon monoxide is reacted with water vapor to form hydrogen and carbon dioxide. These catalyzed reactions are both endothermic. Energy for both catalyzed reactions is obtained by heat from flue gas accomplished by combustion. Sensible heat contained in a gaseous mixture from catalyzed reactions is subjected to a heat exchanger to transfer heat to air utilized for partial combustion and producing a gaseous mixture of reduced sensible heat thereby producing a gas containing hydrogen derived from a biomass.

Characteristics of the invention include:

Producer gas is derived from partial combustion of a biomass.

Complete combustion of remains from partial combustion is performed by heated air.

Flue gas is employed to replace heat of endothermic reactions.

Hydrogen is obtained by catalytic reactions of a producer gas

Moisture content of a biomass is reduced by a dryer supplied from a flue gas

Energy released from a biomass combustion is substantially consumed in the method.

The gas containing hydrogen , derived from a biomass, is separated from the gas to produce hydrogen substantially devoid of impurities.

The method is generally continuous.

Hydrogen contained in a gas may be is stored in a medium and separated from the gas for release.

Air is supplied to maintain a heat balance within the method

Hydrogen, derived from a biomass, generally provides energy to operate a fuel cell.

# BRIEF DESCRIPTION OF THE DRAWINGS

The features that are considered characteristic of this invention are set forth in the appended claims. This invention, however, both as to its origination and method of operations as well as additional advantages will best be understood from the following description when read in conjunction with the accompanying drawings in which:

**FIG. 1** is a flow sheet denoting the invention as set forth in the appended claims.

**FIG. 2** is a flow sheet denoting a method to remove water from a biomass.

**FIG. 3** is a flow sheet denoting a method to store hydrogen in a medium.

**FIG. 4** is a flow sheet denoting a method to separate hydrogen with a membrane.

# DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the preferred embodiment of the present invention production of hydrogen derived from a supplied biomass is presented. Producer gas, by catalytic essential changes, provide hydrogen and carbon dioxide.

The flow diagram of **Fig. 1** illustrates the general preferred embodiment of the present invention. In the diagram, rectangles represent stages, operations or functions of the present invention and nonessential separate components. Arrows indicate direction of flow of material in the method.

Referring to **Fig. 1,** biomass **10A** is conveyed to gasification stage **12** to furnish producer gas **14,** containing carbon monoxide, by partial combustion with air **16A**. Remaining solids from partial combustion **18** are contained in combustion stage **20** and are subject to complete combustion by heated air **22** to form flue gas **24A** and residue **26** which is subjected to heat exchange stage **28** to heat air **30** and provide residue **32** of reduced temperature. Flue gas **24A** is transported to steam reform catalysis stage **40** which is utilized to provide energy to producer gas, containing carbon monoxide, **14** to provide reformed gas, containing carbon monoxide and water vapor, **14A** and transported to steam shift catalysis stage **42** to produce a gaseous mixture **14B** containing hydrogen and carbon dioxide which is conveyed to heat exchange stage **44** to heat air **16** and furnish heated air **16A** to gasification stage **12** and supply gaseous mixture **14C** of reduced sensible heat. Flue gas **24A,** transported to steam reform catalysis stage **40,** is prevented from contacting producer gas by means of a heat transfer device, unobserved within the drawing, which provides heat for endothermic reactions and flue gas B **24B** of reduced sensible heat.

Similarly, flue gas B **24B** is transported to steam shift catalysis stage **42,** to transfer heat from flue gas B **24B** and generate flue gas C **24C** of reduced sensible heat and produce gaseous mixture **14B.** Residue **26** can remain within combustion stage **20** for heating of air thus requiring an unnecessary heat exchange stage **28** to provide heat air **30.** Flue gas A **24A** is essential to the method to replace endothermic heat of both catalytic reactions. Complete combustion by heated air **22** is required to form a sufficient quantify of flue gas. The remaining solids from partial combustion **18** may be contained in a single vessel for combustion within combustion stage **20** with separate outlets for producer gas **14** and flue gas **24A**.

Referring to **Fig. 2,** flue gas C **24C** is conveyed to biomass dryer stage **46** to provide heat to supplied biomass **10** to remove water and provide biomass of reduced water **10A** and flue gas D **24D** of insubstantial reduced sensible heat to be discarded.

Referring to **Fig. 3,** gaseous mixture **14C** containing hydrogen and carbon dioxide is conveyed to medium storage **48** to store hydrogen within the medium contained within medium storage **48**. Upon storage, hydrogen **36** is released from storage. Gas **38,** not stored within the medium , is separated from the medium for subsequent treatment for ultimate disposal.

Referring to **Fig. 4,** gaseous mixture **14C** containing hydrogen and carbon dioxide is conveyed to hydrogen permeable membrane **50** to allow advance of hydrogen **54**. Gas **52,** un- permeated by the hydrogen permeable membrane, is separated from the hydrogen permeable membrane.